LIQUID HELIUM

Nuclear Cooling

from our Condensed Matter Correspondent

THERMAL contact between a metal and liquid ^{3}He at temperatures of a few mK can be greatly enhanced by adding a small proportion of magnetic impurities to the metal. This important experimental effect has been demonstrated by Avenel, Berglund, Gylling, Phillips and Vetleseter of the Helsinki University of Technology, working in collaboration with Vuorio of the University of Helsinki (*Phys. Rev. Lett.*, **31**, 76 ; 1973).

Temperatures significantly below 1 mK have been reached only through adiabatic nuclear demagnetization, by which the system of nuclei in, for example, a piece of copper can be cooled to a few μK. Unfortunately, however, this technique has been of little practical use, chiefly because of the difficulty of making satisfactory thermal contact at these temperatures. The need, engendered by the recent discovery of new, perhaps superfluid, phases of ^{3}He, to carry detailed investigations of the liquid to well below 1 mK will probably be met, eventually, only through use of nuclear cooling, so it has become a matter of prime importance that a method should be devised for achieving adequate thermal contact between metal and liquid at these temperatures.

When heat, in the form of a net flow of phonons (quantized lattice vibrations, travelling at the velocity of sound), passes across a boundary between two different materials, there is always a discontinuity in temperature across the interface as a result of the so-called Kapitza boundary resistance, R_B. This phenomenon, which arises from the different velocities of sound in the two materials, becomes very much more marked as the temperature is reduced (in fact $R_B \propto T^{-3}$), and the discontinuity takes a particularly large value in the case of a helium to metal interface simply because the acoustical velocity mismatch is then especially severe. For this reason, it usually takes an exceedingly long time to establish thermal equilibrium between liquid ^{3}He and a solid with which it is in thermal contact.

Abel, Anderson, Black and Wheatley, then of the University of Illinois, were therefore surprised to observe that thermal contact between liquid ^{3}He and the paramagnetic salt cerium magnesium nitrate (CMN) was anomalously good (*Phys. Rev. Lett.*, **16**, 273 ; 1966). They found, in fact, that the thermal equilibrium time for a mixture of powdered CMN and ^{3}He was only a few tens of seconds, considerably less than the time predicted from a value of R_B calculated on the basis of phonon conduction. Furthermore, the measured R_B varied as T^{-1} rather than T^{-3}, which suggested that heat was being transferred across the interface by an entirely different mechanism.

Leggett of the University of Sussex and Vuorio were later able to explain this phenomenon in terms of a direct interaction between the magnetic moments of the ^{3}He nuclei and the electronic spin magnetic moments of the cerium ions in the CMN (*J. low temp. Phys.*, **3**, 359 ; 1970). Their proposal was that most of the heat is carried across the interface, not in the form of phonons, but as a result of the electronic spin system in the CMN being able to "talk" directly to the nuclear spin system of the ^{3}He, and they were able to show that this process would result in a T^{-1} dependence of R_B, as observed. It was suggested, therefore, that, by a similar mechanism, R_B between ^{3}He and a metal might be reduced if the metal were "doped" with a small proportion of magnetic ions, which could then communicate directly with the ^{3}He nuclei. The experiment now reported by the Helsinki group shows unambiguously that this is so.

In one experiment, a thin palladium foil of area 254 cm^2 and containing 32 p.p.m. of iron was immersed in liquid ^{3}He. The foil was welded to a piece of high purity copper whose temperature, and thus that of the foil itself, could be derived from measurement of its nuclear magnetic susceptibility. The temperature of the ^{3}He was determined by measuring the magnetic susceptibility of powdered CMN immersed in it. Heat was supplied at a constant rate, and the temperature difference between the foil and the ^{3}He was carefully monitored as the whole assembly gradually warmed up. R_B was found to vary as T^{-1}, just as for an interface with CMN, and at 4 mK was fifty times smaller than would have been expected for a pure palladium foil, assuming conduction only by phonons.

Although R_B will need to be reduced by an even larger factor before nuclear demagnetization can become a really useful tool for cooling liquid ^{3}He, the results of the Helsinki experiment are distinctly encouraging.

Subduction Beneath Barbados

ALTHOUGH most of the Atlantic continental margins are not plate boundaries, there are a few border areas where oceanic lithosphere is thought to be descending. One of these lies in the vicinity of the Lesser Antilles island arc where, although crustal structure is known in very general terms, the precise position and nature of the subduction zone have remained unclear. In next Monday's *Nature Physical Science* (August 20), however, Westbrook *et al.* report the results of a geophysical survey which has enabled them to present a more detailed model of the nature and behaviour of the descending crust near Barbados.

The principal data come from an east–west seismic refraction line to the east of Barbados, and show that the Moho dips by 1.3° or 2.0° towards the island (assuming velocities of 8.1 or 8.3 km s^{-1}, respectively, beneath the Moho) and that the oceanic layer dips in the same direction by about 1°. What these results mean is that over 50 km away from, and to the east of, Barbados, at least, there is no significant descent of the oceanic lithosphere. But an interpretation involving a combination of the seismic data, gravity observations and other seismic results from the west of Barbados shows that closer in towards the island the oceanic crust begins to dip much more steeply from both the east and west. At the same time the sediment gets thicker from both directions until beneath Barbados itself it reaches a maximum thickness of about 18 km.

Thus although there is a long gentle slope downwards from the east in the oceanic lithosphere, the subduction zone proper only begins beneath Barbados itself—and this is confirmed by the lack of earthquake activity to the east of the island. Moreover, the sedimentary thickening towards a maximum indicates a sediment-filled trench structure, also beneath the island. Reflexion experiments show that the sediments themselves are deformed, both in the trench structure and over the relatively flat lying oceanic crust to the east. Westbrook and his colleagues attribute this deformation to the piling up of sediment as the Atlantic ocean floor moves westwards beneath. Most of this piling up occurs to the east of Barbados, although the reflexion data also suggest that some sediment is being thrust over the plate to the west of the Barbados Ridge.

Finally, assuming that the natural thickness of the sediment accumulating on the westward-moving oceanic crust has remained roughly constant over the estimated 60 million-year age of the Lesser Antilles, the volume of sediment now in the Barbados pile would imply an average subduction rate of 1.0 cm yr^{-1}. This compares with a figure of 0.52 cm yr^{-1} derived from the fact that the leading edge of the descending lithosphere, assumed to be represented by the lower limit of earthquake foci, has apparently reached a depth of 200 km during the same 60 million years.